



# Fundamental Aeronautics Program

## *Subsonic Rotary Wing Project*

### Large Civil Tiltrotor Flight Control and Handling Qualities Simulation Investigations

Colin Theodore  
Technical Lead  
Flight Dynamics & Controls

NASA:  
William Decker  
Carlos Malpica

US Army:  
Chris Blanken

San Jose State Foundation:  
Ben Lawrence

Monterey Technologies:  
Jim Lindsey

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# Outline

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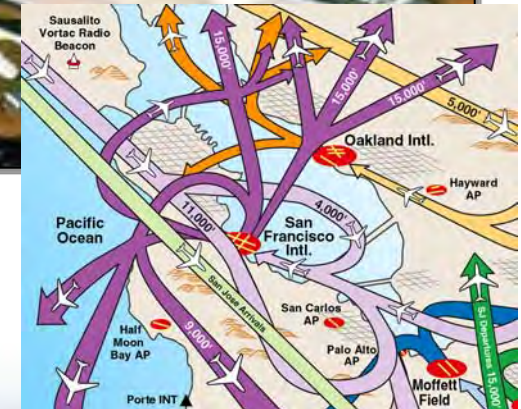


- Motivation / Objectives
- Previous Simulations
- Current 2010 Simulation
- Preliminary Results
- Conclusions
- Future Work

# Rotary Wing Vehicles in NextGen



- SRW Goal: Radically improve the transportation system using rotary wing vehicles by increasing speed, range and payload while decreasing noise and emissions
- Systems studies show: Large, advanced technology tiltrotors consistently outpace other rotorcraft configurations in the ability to meet the civil mission
- Flight Dynamics and Controls deals with pilot and cockpit technologies as a bridge between the vehicle and operations concepts





# SRW – Five Technical Challenges

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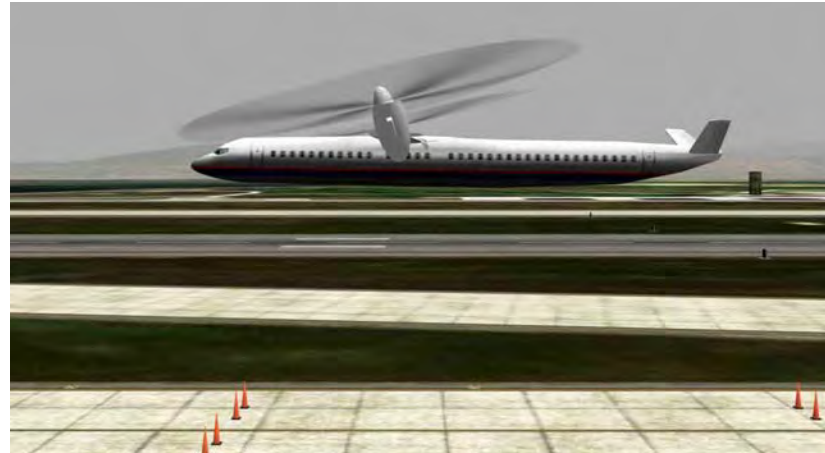
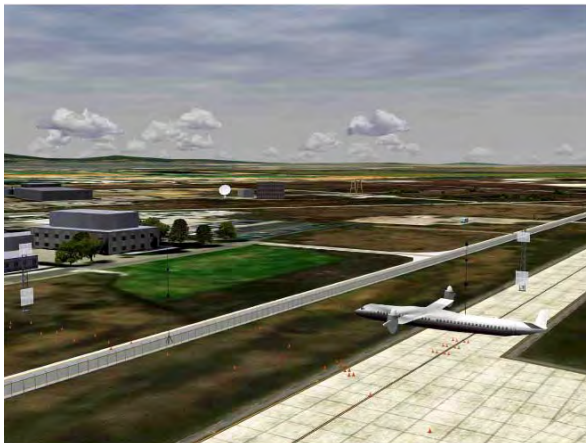
- **Integrated Aeromechanics/Propulsion System (IAPS)**: Develop and demonstrate technologies enabling variable-speed rotor concepts
  - **Goal**: 50% main rotor speed reduction while retaining propulsion efficiency
  - **Benefits**: very high-speed, efficient cruise; efficient hover; reduced noise, increased range
- **Actively-Controlled, Efficient Rotorcraft (ACER)**: Simultaneously increase aerodynamic efficiency, control dynamic stall, reduce vibration, reduce noise
  - **Goal**: 100 kt speed improvement over SOA; noise contained within landing area; 90 pax /10 ton payload
  - **Benefits**: very high-speed, efficient cruise; efficient hover; reduced noise; improve ride quality
- **Quiet Cabin (QC)**: Reduce interior noise and vibration
  - **Goal**: Internal cabin noise at level of regional jet with no weight penalty
  - **Benefit**: passenger acceptability; increased efficiency through weight reduction
- **NextGen Rotorcraft**: Foster, develop and demonstrate technologies that contribute to the commercial viability of large rotary wing transport systems in NextGen.
  - **Goal**: mature technologies (icing, crashworthiness, condition based maintenance, low noise flight operations, damage mitigation, etc) needed for civil, commercial operations
  - **Benefit**: enables vehicle acceptability for passengers and operators
- **High Fidelity Validated Design Tools**: Develop the next generation comprehensive rotorcraft analysis and design tools using high-fidelity models.
  - **Goal**: first-principles modeling in all disciplines; ensure design tools are hardware flexible and scalable to a large numbers of processors
  - **Benefit**: Reduce design cycle time and cost of NextGen rotorcraft; increase confidence in new concept design



# Large Rotorcraft Flight Control and HQ Studies



- Objectives:
  - Develop understanding of the flight control and HQ effects of unique characteristics of large helicopters, including tilt-rotors: low bandwidth response, large pilot offset
  - Develop handling qualities and control system requirements for large helicopters
- Approach:
  - Series of experiments to systematically study fundamental Handling Qualities and control system effects throughout flight envelope and airspace integration
  - Piloted simulation experiments in Vertical Motion Simulator (VMS)
  - Partnership with US Army and helicopter industry
- Current status:
  - Three successful hover and low speed experiments in the VMS (2008, 2009 & 2010)



# Large Civil Tiltrotor 2<sup>nd</sup> Generation (LCTR2)



- NASA's notional high-speed configuration:
  - Baseline gross weight 103,600lb (47,000kg)
  - 65ft (20m) Diameter rotors, 107ft (32.6m) Wingspan
  - Cockpit 40ft ahead of Center of Gravity
- Capabilities:
  - 90 passengers, Speed 300kts, Range 1000nm (nominal)

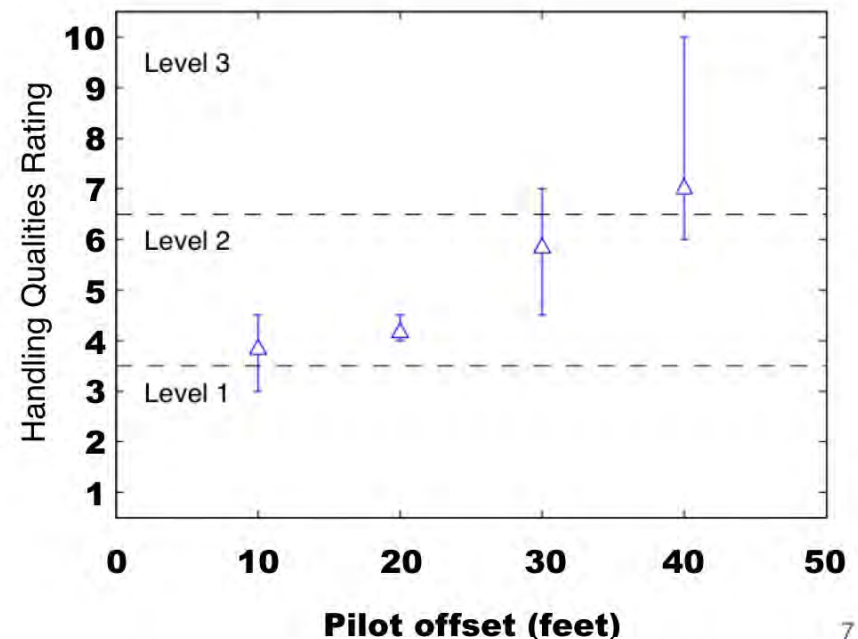
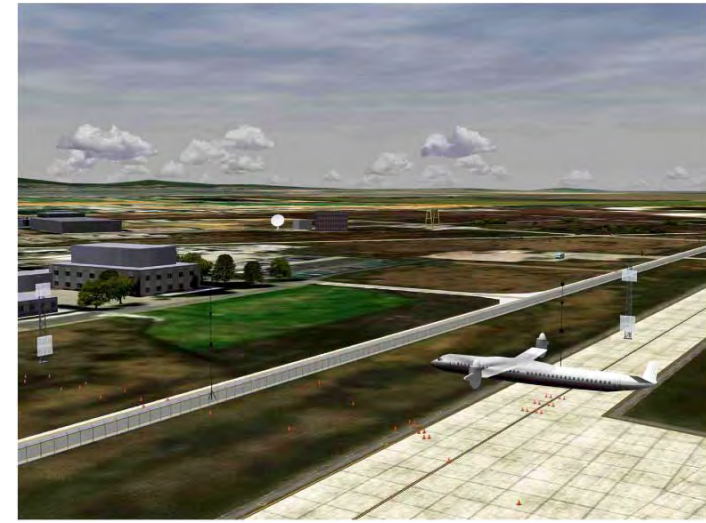


Reference: Acree, C. W., Hyeonsoo, Y., and Sinsay, J. D., "Performance Optimization of the NASA Large Civil Tiltrotor" International Powered Lift Conference, London, UK, July 22-24, 2008

# 2008 & 2009 Experiments



- 2008 – Studied basic effects of rotorcraft size on piloted handling qualities in hover
  - UH-60 Blackhawk, CH-53, and LCTR
  - LCTR only achieved Level 2 Handling Qualities with Attitude Command-Attitude Hold (ACAH)
  - Impact of large (40 feet) cockpit to CG distance immediately evident
- 2009 – Investigated fundamental pitch, roll and yaw response requirements and effect of C.G. to pilot offset on handling qualities
  - LCTR experiment in hover with fixed nacelles
  - Level 2 Handling Qualities was best that could be achieved with ACAH control
  - Ride quality degrades due to pitch/heave coupling with larger pilot offsets
- *Key Result: Advanced control modes required for improved Handling Qualities*

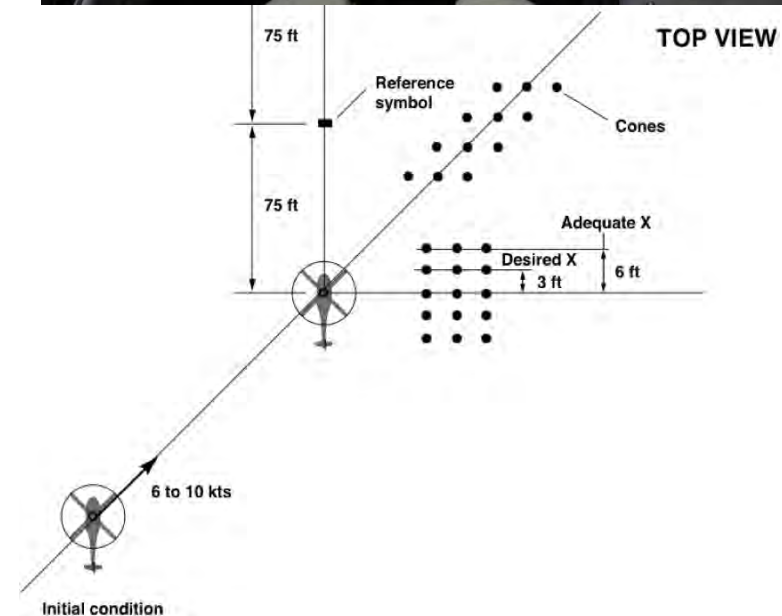




# 2010 LCTR Experiment



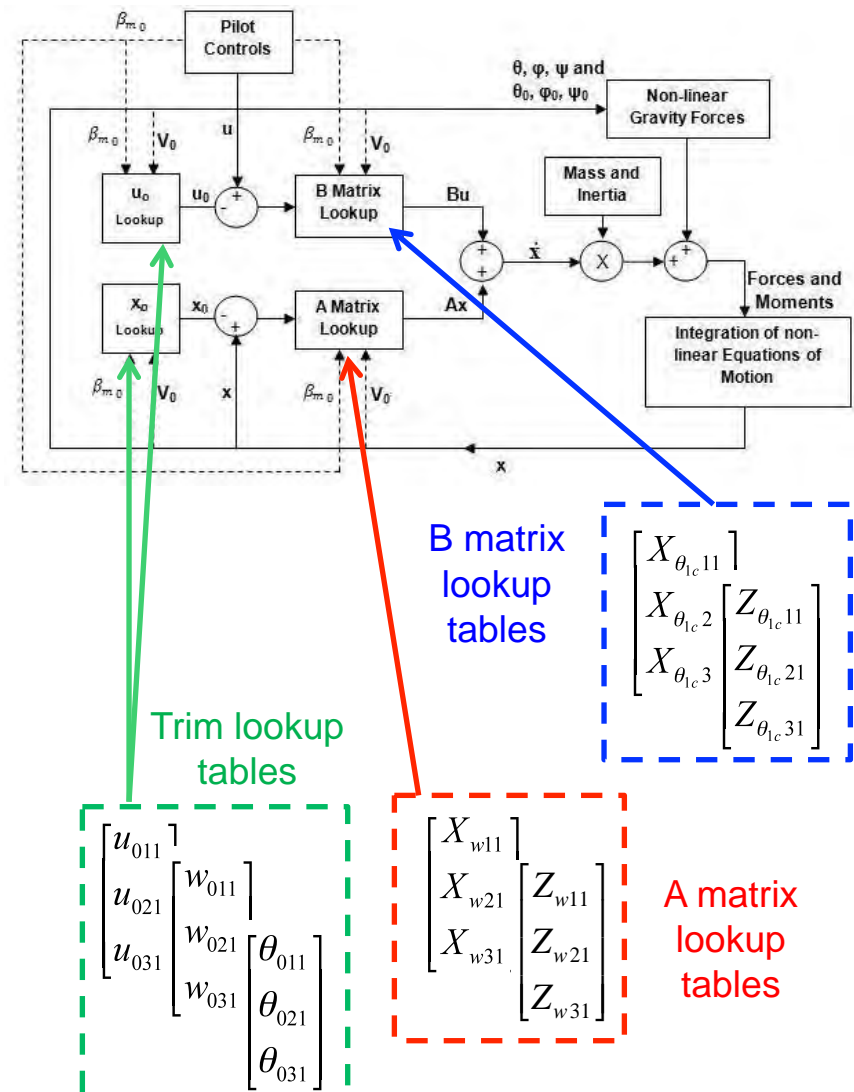
- Objectives:
  - Investigate Translational Rate Command (TRC) using automatic nacelle motion
  - Evaluate Handling Qualities beyond hover into the low speed flight regime
- Control Modes:
  - ACAH
  - TRC
  - Hybrid (TRC with non-zero roll attitude)
- Evaluation maneuvers:
  - Precision hover task
  - Lateral reposition
  - Depart/Abort (ACAH mode only)



# Vehicle Dynamics Modeling



- New modeling requirements:
  - Movable nacelles from hover to 60 deg
  - Model valid from hover to 60 knots
  - Independent rotor control to enable TRC
- Modeling approach:
  - Linear models from CAMRAD II
  - Linear Parameter Variation (LPV) stitched model
  - Independent parameters:
    - Forward speed
    - Nacelle angle
- Addition of nacelle degree of freedom
  - Modeled as 2<sup>nd</sup> order dynamic system
  - Fixed bandwidth and damping
  - Variable rate and position limits



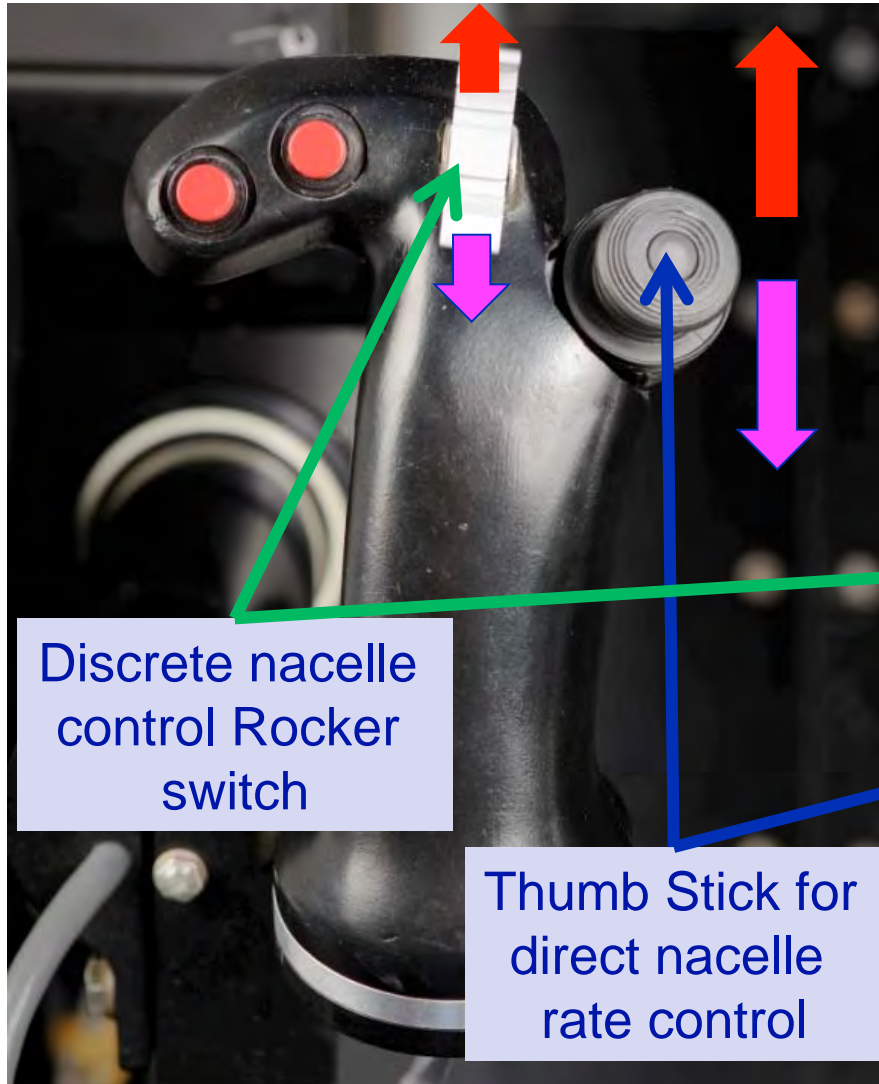
# Experiment Variables

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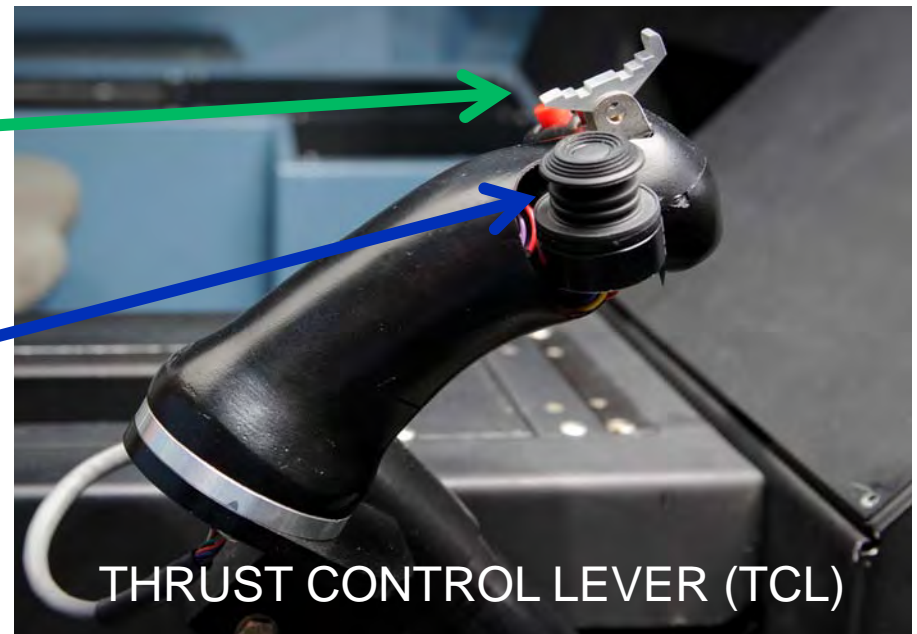


- Variables:
  - Control system response type: ACAH, TRC, Hybrid
  - Nacelle actuator rate and position limits in TRC mode
  - TRC inception methods of thumb stick and center stick
  - TRC inceptor stick sensitivity
- Experiment performed in July 2010:
  - 4-weeks of motion in VMS
  - 10 pilots from NASA, US Army, Marine Corps, rotorcraft industry

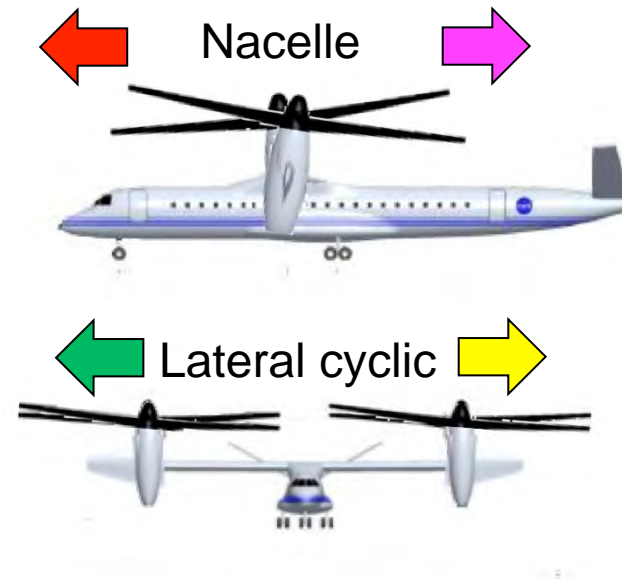
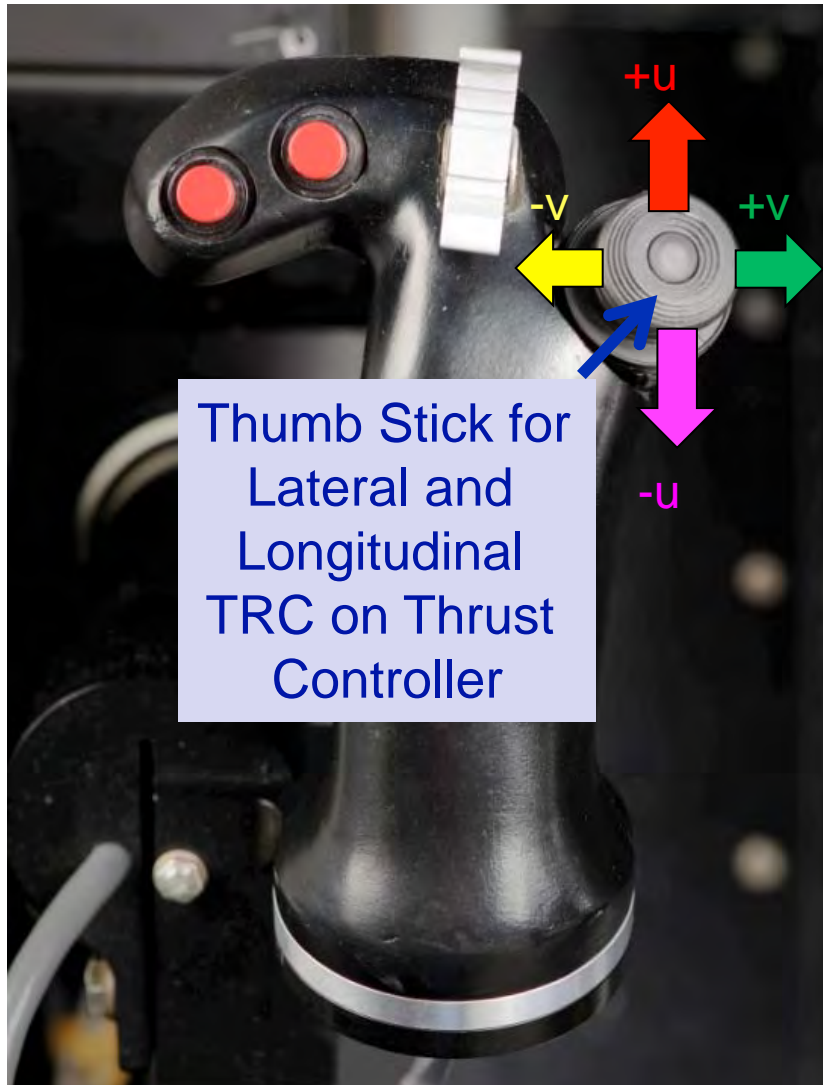
# Direct Nacelle Control (ACAH)



Discrete 'Beep' Mode		Direct rate command
Stops at 95°, 86°, (80°), 75°, 60°	±2 deg/s	±7.5 deg/s max



# Translational Rate Control



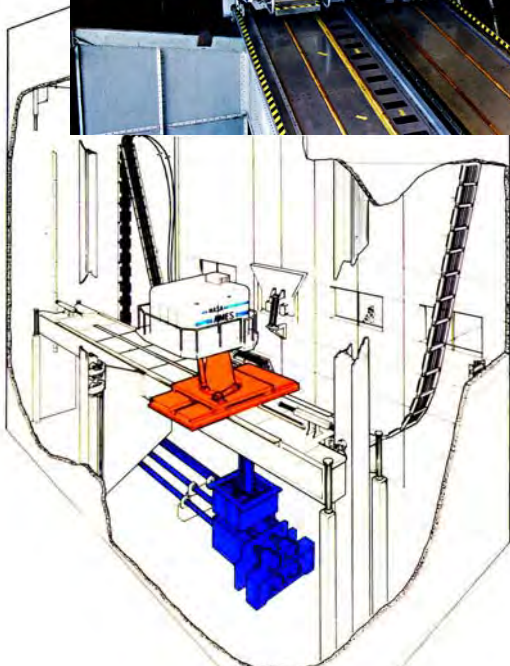
- Thumb stick provides 2-axis proportional control of longitudinal and lateral TRC
- TRC also commanded through center stick
- Nacelle actuators featured separate configurable angle and rate limits in TRC



# Vertical Motion Simulator (VMS)



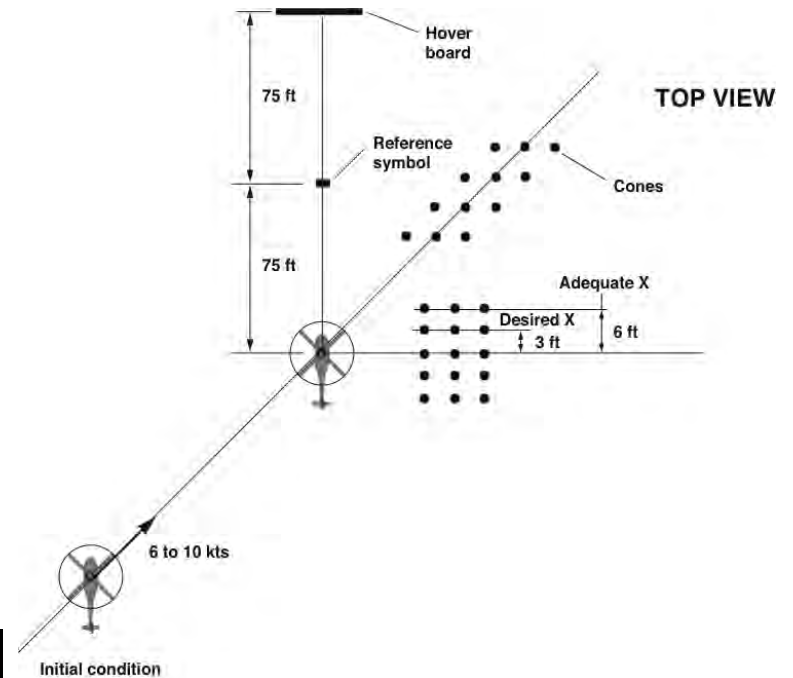
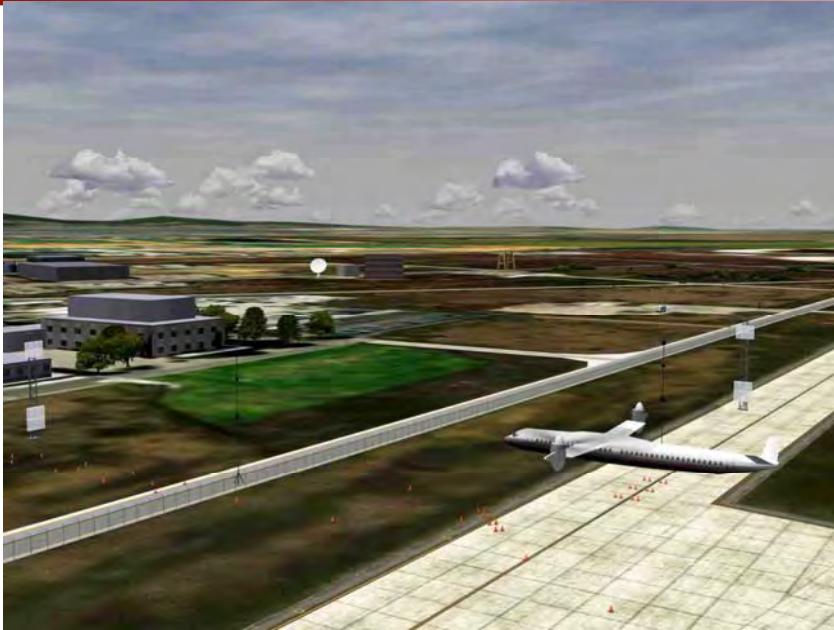
Overview of two-seat transport cockpit



Large motion platform



# Precision Hover Task Description



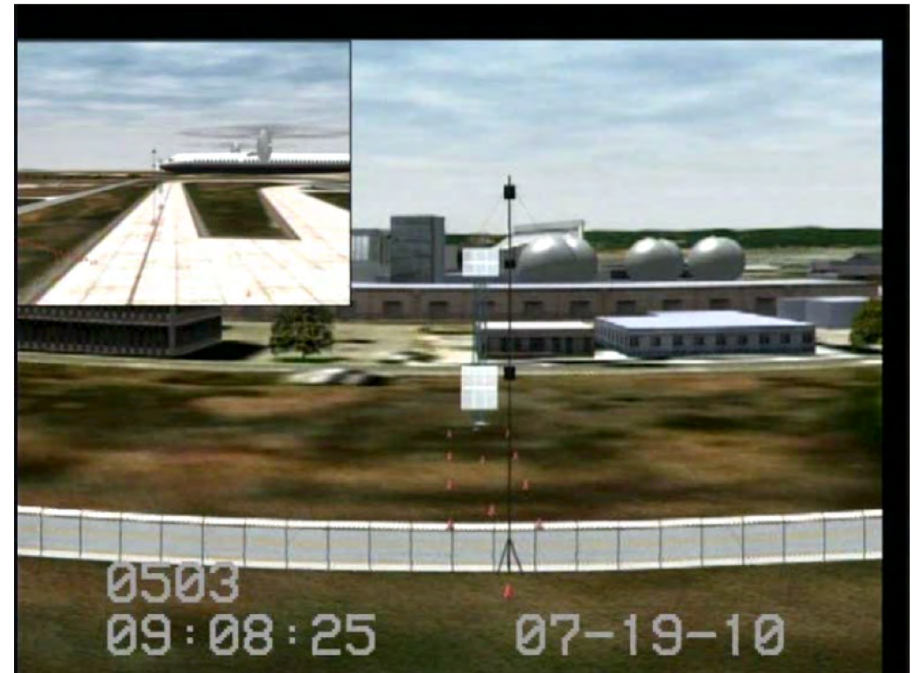
1. Diagonal translation @ 6 - 10 kts.
2. Decelerate within 5 sec.
3. Station keeping for 30 sec.



# Control Comparison (Hover)

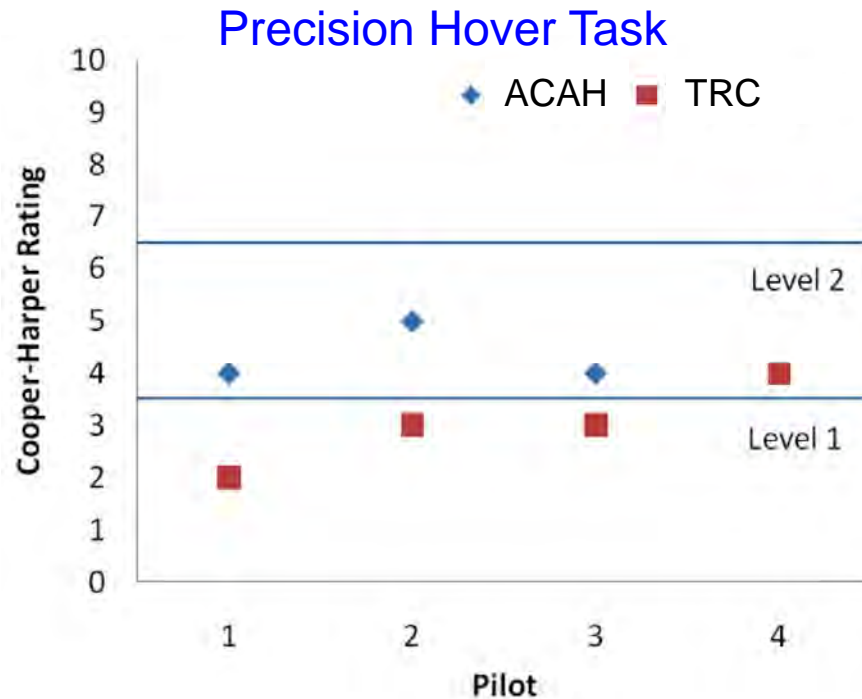


Attitude  
Command  
Attitude Hold



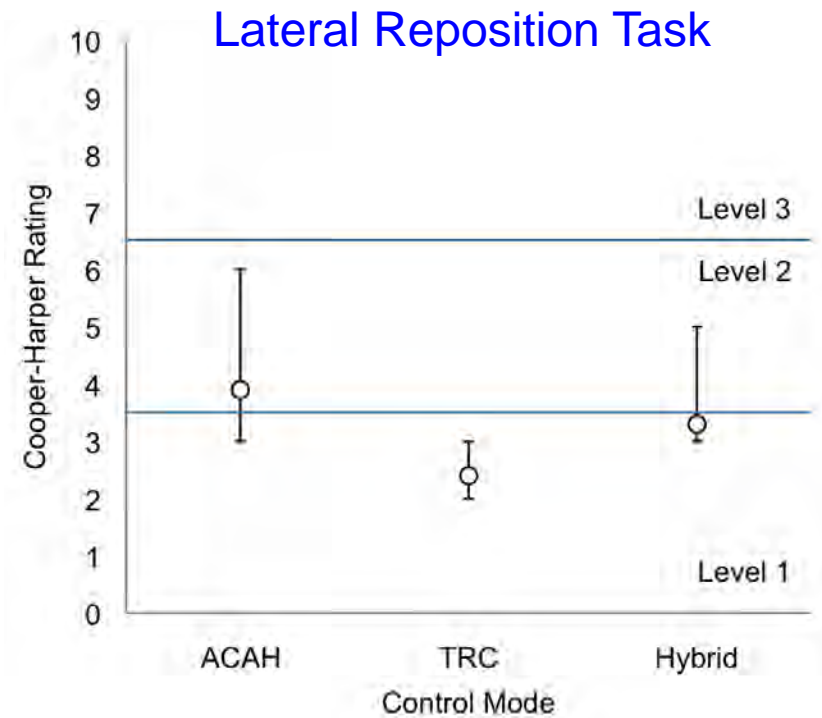
Translational  
Rate Control

# Preliminary Results



Precision hover task evaluations for 4-pilots

Level 1 HQ achieved for 3 of 4 pilots with TRC control mode



Lateral reposition evaluations for all pilots combined

Level 1 HQ with TRC for all pilots with low scatter in data

# Depart/Abort Maneuver



ACAH – Nacelles being controlled directly by pilot





# Conclusions

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- Current achievements:
  - Possible to achieve Level 1 Handling Qualities in hover and low speed flight with a TRC control system and automatic nacelle motions
  - Understanding of fundamental effects of aircraft size (mass and inertias) and pilot to C.G. offset on handling qualities
- 2011 VMS Experiment:
  - Continue hover/low speed HQ work with advanced control model (TRC and others) and low bandwidth nacelle actuator response
  - Study initial terminal area operations:
    - Expand speed envelope out to 120 knots
    - Develop initial set of evaluation tasks and metrics

# Future VMS / Handling Qualities Research

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- 2011 – 2012 Experiments:
  - Continue hover/low speed HQ work with advanced control modes (TRC and others), control mode switching and low bandwidth actuator response
  - Assess aspects of operation of large rotary wing vehicles in terminal areas
- 2013 – 2014 Experiments:
  - Handling Qualities and pilot workload analysis of candidate advanced acoustics flight profiles
  - Develop pilot interface guidance displays to support advanced flight profiles
- 2015 – 2016 Experiments:
  - Full-envelope mission simulation with rotor speed shifting and noise abatement guidance using candidate NextGen operating procedures
- 2017 – 2018 Experiments:
  - Real-time coupling of LCTR VMS simulation and air-traffic simulations for NextGen integration studies and experimentation

